# Computing LISA Far Field Phase Patterns

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## Abstract

The telescope has been the astronomical tool of choice since 1609, when Galileo first introduced it to the science community. Without it, the discovery of sunspots, Jupiter's moons, and Saturn's rings may not have occurred for many years. Optical instruments have been key in our exploration of the universe and will continue to be essential in our endeavor to understand it. Over the years, these instruments have expanded beyond the visible spectrum into the X-Ray, Ultraviolet, and Infrared spectra. The Laser Interferometer Space Antenna (LISA) takes astronomy to the next level by searching for gravity waves. A combination of lasers and micronewton thrusters are used to maintain the 5x10^9 m distance between each of the 3 satellites that make up LISA. The constant station keeping maneuvers required by LISA will effect a wobble in the sensitive optics of the spacecraft. The purpose of this project is to model the optics at the picometer level and test the accuracy of such predictions by using quad precision variables.

Fig. 1

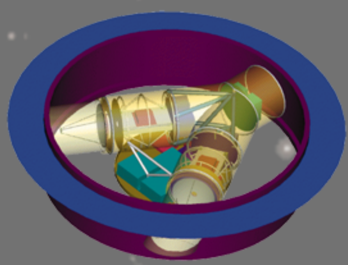

Fig. 2

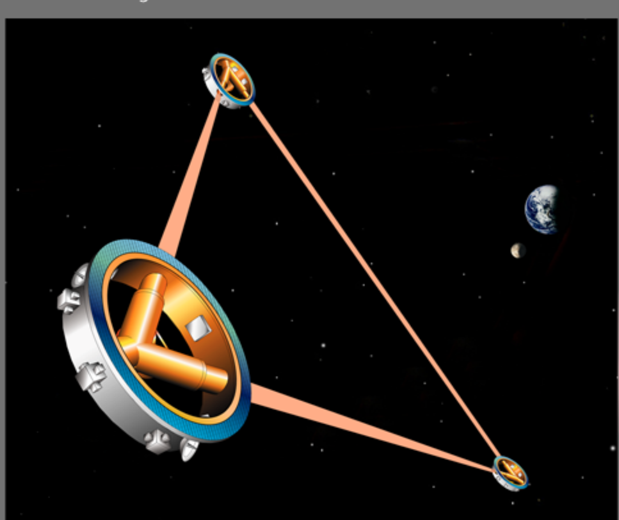

Fig. 3

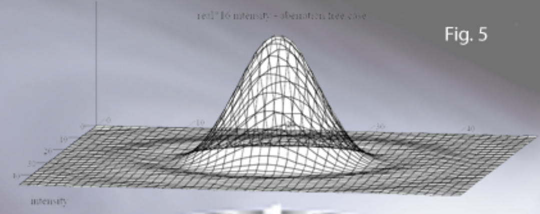

Fig. 5

$$A(X.Y.Z)\cdot e^{i\frac{2\pi}{\lambda}R}\cdot e^{i\frac{2\pi}{\lambda}\phi(X,Y,Z)} = \iint E(x.y.z)\frac{e^{i\frac{2\pi}{\lambda}(Z_n + S)}}{S}dxdy \quad \text{Eq. 1}$$

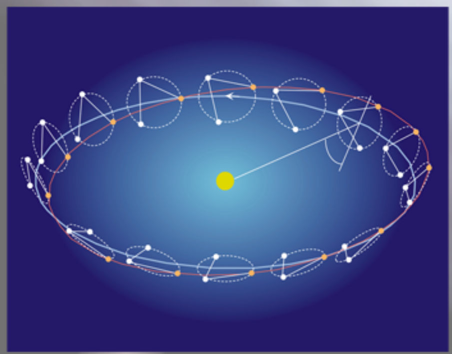

Fig. 4

## Background

Gravitational waves are ripples in space-time created by the movement of massive bodies. Figure 1 shows an artist's conception of the interaction between two supermassive black holes and the resulting gravitational waves. LISA will act as a sort of buoy floating in space that moves with any passing gravitational waves. LISA is comprised of 3 identical spacecraft (seen in figure 2) located 5 million kilometers apart. Each craft projects two lasers—one to each of the other two spacecraft—as can be seen in figure 3. Additionally, each craft contains two freely floating test masses that act as mirrors in an interferometer. Because gravitational waves are so faint, it is critical that the test masses are guarded against any forces other than those trying to be detected. That is, solar pressure or even the electromagnetic fields from the craft's own avionics could affect the test mass. Little thrust is required to keep each craft centered about its test mass. Therefore, each craft is equipped with micronewton thrusters to maintain the position shown in figure 4. The lasers maintain a wavelength of 1064 nanometers; however, since they are separated by 5 million kilometers, the expected distance change due to a gravitational wave corresponds to about 10 picometers or 1.0*10^-11 meters. This is only 10^-5 waves and it is in this merger of picoscopic and macroscopic realms that a need for serious computing power arises.

## Modeling

Equation 1 describes the far field and is known as the diffraction integral. X, Y, and Z are the far field variables that lie on a sphere of radius R centered on the center of the exit pupil of the laser. Radius R is the distance between LISA spacecraft or about 5,000,000 km. The equation is integrated over the area of the exit pupil and Zn is the exit pupil aberration. Notice that in order to perform a numerical approximation of the diffraction integral, a very large number (s measured in millions of kilometers), must be added to a very small number (Zn measured in fractions of a wave length). This difference is much too large to be modeled with traditional double precision (32-bit) computers. We therefore look to a 64-bit machine or quadruple precision Digital Alpha computer supported by a FORTRAN compiler. Without any aberration, the diffraction integral can be numerically integrated to produce the graph of intensity shown in figure 5.

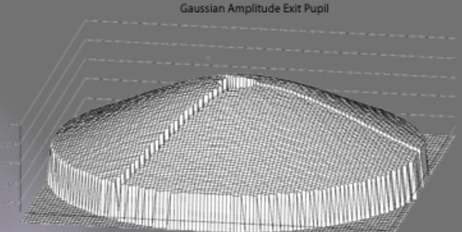


Fig. 6

Even the best optical designs do not create perfect images, however.
Therefore, the model is adjusted for certain variations: zernike, spider thickness, spider number, and Gaussian distribution. A spider refers to the structure that supports the secondary mirror. These are actually struts, and depending on the number of struts and the thickness of each strut, a great deal of light may be lost. The effect of spiders can be seen in figure 6 (Obscuration). This figure also shows a typical Gaussian distribution in which some light is to the edge of the exit pupil. Specific zernike polynomials are fitted to these far field phase variations in an effort to model a defocused variation and an astigmatic pupil. Zernikes alter the shape of the wave front as can be seen in figure 7. These methods will be used in concert to predict how LISA's optics will be affected by different combinations of optical interference.

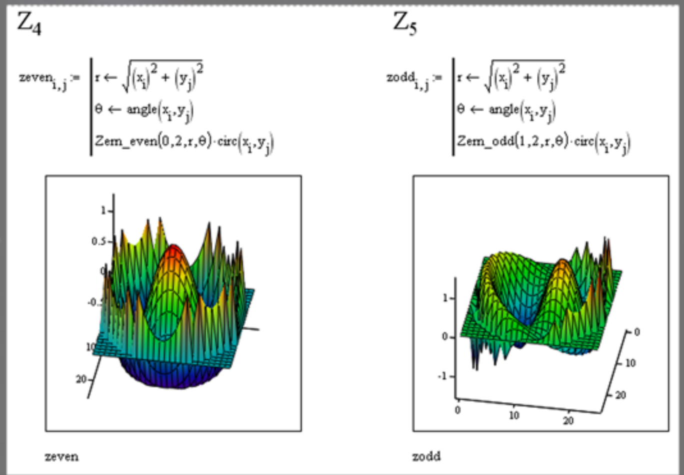


Fig. 7